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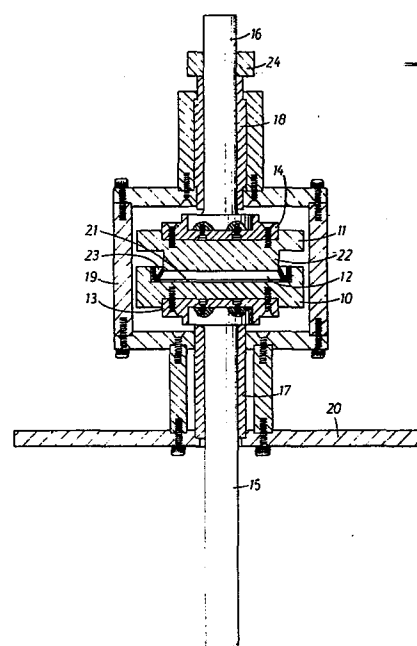
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Improvements relating to electroviscous fluid-actuated devices.

An electroviscous fluid actuated device, such as a clutch, comprises relatively rotatable electrode plates (10, 11) defining a gap (12) therebetween of 2 mm to 5 mm width. An electroviscous fluid in the gap (12) becomes «solid» when a pulsating d.c. is applied to the plates. Slippage can be controlled by controlling the peak value of the pulsating d.c.

The electroviscous fluid comprises a suspension of starch in silicone oil, having a ratio by weight of at least 1:1.



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DESCRIPTIONIMPROVEMENTS RELATING TO ELECTROVISCIOUS FLUID-
ACTUATED DEVICES.

5 The present invention relates to devices designed to be actuated by means of an electroviscous fluid and to electroviscous fluid compositions.

10 When certain fluids are subjected to an electrostatic potential they become increasingly viscous or even solid. This effect, sometimes called the Winslow effect, is broadly described in Winslow's U.S.A. Patent No.2,417,850. Electroviscous fluids exhibiting this property are fluids which comprise a suspension of particles generally having a high dielectric constant in a fluid generally having a low dielectric constant.

15 The particles are generally hydrophilic particles to which water is absorbed to impart the high dielectric property. In devices actuated with the use of an electroviscous fluid, the fluid is contained in a small gap between two electrically conductive members which

20 serve as electrodes. When the device is a valve, the fluid can flow freely through this gap. When the device is a mechanical device, such as a clutch or brake, the two members can be moved freely relative to one another whilst maintaining the gap. When an

25 electric potential is applied to the electrodes, the fluid, in effect, solidifies thereby stopping fluid flow through the gap in the case of a valve or preventing relative movement between the electrodes, in the case of a brake or clutch.

30 The pressure which the device is capable of withstanding in the case of a valve or the force or torque which the device is capable of withstanding in the case of a clutch or brake is dependent amongst other things on the electrostatic potential applied between the

35 electrodes. With an increasing electrostatic field, the shear force which the fluid is capable of

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withstanding is progressively increased until the point is reached when the fluid will no longer flow and effectively becomes solid. In the case of a valve, the reaching of this point means that the valve is fully closed and, in the case of a clutch or brake,
5 the reaching of a solid state results in there being no slipping.

It has now been found that a pulsating electrostatic field has a number of surprising
10 advantages when used to influence an electroviscous fluid.

Thus, according to one aspect of the present invention, an electroviscous fluid-actuated device having electrodes defining a gap therebetween, such
15 gap containing an electroviscous fluid, is provided with means for applying a pulsating direct voltage to the electrodes.

Advantages of the use of a pulsating direct voltage are that a better control of slippage, in the
20 case of a clutch or brake, a smaller power consumption and a reduced liability to electrostatic discharge.

Various fluids have been tried as electroviscous fluids. Hitherto the phenomenon by which electroviscous fluids exhibit their electroviscous
25 properties has not been clearly understood and electroviscous fluid-actuated devices have up to now found little commercial application, no doubt at least in part due to the weakness of the electroviscous fluid solidified under the influence of the electro-
30 static field.

According to another aspect of the present invention, an electroviscous fluid comprises a suspension of particles in a liquid, the ratio by weight of particles to liquid being 1:1 at least and
35 preferably not more than 1.8:1. The electroviscous

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fluid according to the invention may thereby be of
pasty consistency.

According to a further aspect of the present
invention, the liquid component of an electroviscous
5 fluid is a silicone fluid. The viscosity of the
silicone fluid is advantageously between 1 centistoke
and 500 centistokes and is preferably about 350
centistokes. The particulate material of an electro-
viscous fluid according to the invention is preferably
10 starch but may be silica gel or a mixture of silica
gel and starch.

The present invention will be further described,
by way of example, with reference to the accompanying
drawing which is a sectional elevation of a clutch
15 constructed in accordance with the invention to be
actuated with the use of an electroviscous fluid.

Referring to the drawing, a clutch comprises a
lower clutch plate 10 and an upper clutch plate 11
spaced apart to define a gap 12 therebetween. The
20 clutch plates 10 and 11 are of electrically conductive
material or at least their respective surfaces
defining the gap 12 are made of electrically
conductive material. The plates 10 and 11 are secured
by means of insulators 13 and 14 to vertically aligned
25 shafts 15 and 16 respectively. The shafts 15 and 16
are journaled by means of bearings 17 and 18 in a
housing 19 mounted to a support 20. By way of
example, the shaft 15 may be the input shaft driven by
a suitable motor and the shaft 16 may be the output
30 shaft which operates a mechanism to be driven.

Electrical connections are made to the clutch
plates 10 and 11. These may be effected by means of
carbon brushes but are preferably made by means of
leaf springs (not shown) which bear respectively
35 against the lower and upper faces of the plates 10 and
11. By way of example, the leaf spring contacting the

upper plate 11 may be connected to earth and the leaf spring contacting the plate 10 will then be connected to a suitable source of high voltage, preferably a variable high voltage and, in the preferred embodiment of the present invention, a pulsating d.c. voltage. In the case wherein the upper plate 11 is earthed as suggested, the insulator 14 acts as a safety means to avoid the risk of a high potential being applied to the shaft 16 in the event that the earthing through the leaf spring fails and the plates 10 and 11 at the same time come into physical engagement with one another or an electrical breakdown between the plates 10 and 11 takes place.

In order to retain an electroviscous fluid in the gap 12, the lower plate 10 is formed with a circular recess 21 and the upper plate 11 is formed with a circular spigot 22 which extends into the recess 21 with axial and radial clearance. To avoid the risk of the electroviscous fluid being flung out of the recess 12 under the influence of centrifugal force, a seal 23 of resilient electrically insulating material can be disposed around the periphery of the recess 21 so that a sealing lip on the seal 23 lightly engages the lower end of the cylindrical periphery of the spigot 22.

The confronting faces of the clutch plates 10 and 11 defining the gap 12 must be accurately machined so as to be perpendicular to the vertical axis defined by the shafts 15 and 16. In the simple illustrated embodiment of the invention, a flange at the upper end of the shaft 15 rests on the bearing 17 under gravity to accurately and positively define the axial position of the clutch plate 10. A collar 24 is secured to the upper shaft 16 by means of a suitable grub screw (not shown) or other device and rests under gravity against the upper end of the bearings 18 in order to

accurately and positively define the axial position of the upper clutch plate 22. The dimension of the gap 12 is thereby accurately defined.

5 A typical dimension for the gap 12 is 2 to 3 mm. If the gap is substantially larger than this, e.g. up to 5 mm, more power must be applied between the electrodes in order to obtain a given electrostatic field between the electrodes.

10 A preferred electroviscous fluid is a fluid comprising a suspension of starch in silicone oil having a viscosity of about 350 centistokes, the ratio of starch to oil by weight being at least 1:1 and preferably 1.5:1. A substantial further increase in the ratio above 1.8:1 is undesirable as it has been
15 found to render the fluid susceptible to electrical breakdown.

The paste-like electroviscous fluids according to the invention have been found to have the further advantage that they are not so prone to settling out
20 and retain their properties even after the device has remained unused for extended periods of several days or more.

In one particular clutch according to the invention the spigot 22 had a nominal diameter of
25 70mm, thereby defining the areas of the confronting electrode surfaces between which the electroviscous fluid is contained.

In experiments using clutch plates of these dimensions and an electroviscous fluid consisting of a
30 suspension of finely divided starch in silicone oil having a viscosity of 100 centistokes, the clutch was found to be capable of transmitting torques, when the clutch effectively became fully engaged, given by the following table:

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	Ratio of starch to silicone oil (by weight)	Gap (mm)	Potential (KV)	Torque (Nm)
	1 : 1	2	2.5	0.15
5	1 : 1	3	5.0	0.15
	1.5 : 1	3	5.0	0.25

The torque which the clutch could transmit can be further increased by increasing the potential between the clutch plates until a point is reached at which an electrostatic breakdown is liable to occur. It has been found that, if the clutch is mechanically overloaded with the electroviscous fluid fully solidified, cracks tend to develop in the solidified fluid and electrostatic breakdown through these cracks takes place. Whilst a stiffer electroviscous fluid gave better torque transmission and whilst a narrower gap also gave better torque transmission for a given potential, difficulty was experienced in attempting to fill a narrower gap with the stiffer paste.

Whilst the invention has been particularly described with reference to an electroviscous fluid actuated device in the form of a clutch, the invention is not so limited. It may advantageously be used with brakes as well as clutches. In the case of a brake, one of the two plates or equivalent will be fixed and it will be generally convenient to insulate the fixed plate or other member with respect to earth and to apply the high voltage to such fixed plate or other member. The rotating plate or complementary member would then be earthed through a leaf spring or other form of electrical contact.

An electroviscous fluid-actuated brake in accordance with the invention may advantageously be used in an anti-skid brake system wherein repeated and rapid on and off operations of the brake are

necessitated. Because the brake can be directly actuated electrically, the various relay valves normally associated with anti-skid systems are avoided.

5 It has surprisingly been found that the risk of electrostatic breakdown of the electro-viscous fluid is substantially reduced if a rapidly fluctuating or pulsating d.c. or a pulsed d.c. of a frequency of, for example about 60 Hz is used rather than a continuous uniform or constant d.c. Another advantage of the use
10 of a pulsed d.c. is that the power consumption is reduced, it being possible to keep the electroviscous fluid solid even with a pulsating electrostatic field. A further advantage is that more accurate torque control can be maintained during slippage.

15 Whilst electroviscous fluid-actuated devices have been described in the form of clutches and brakes, other applications of the invention are envisaged. One such application is to a workpiece holder for a lathe, more specifically a chuck. Another application
20 is to vehicle suspension systems wherein springs and shock absorbers may be replaced by electroviscous fluid-actuated devices which are controlled by a microprocessor to vary damping characteristics. A further application is the control of fluid flow to
25 hydraulic actuators.

It has been found that electroviscous fluid-actuated devices consume such a small current, of the order of 10^{-5} to 10^{-10} amps, that the current cannot be accurately measured by relatively simple
30 techniques. Accordingly, the power consumption of the device is extremely low.

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CLAIMS

1. An electroviscous fluid-actuated device comprising electrodes (10,11) defining a gap (12) therebetween, such gap containing an electroviscous fluid, characterised by means for applying a pulsating
5 direct voltage to said electrodes (10,11).

2. A device according to claim 1, in which the frequency of the pulsating direct voltage is up to about 60 Hertz.

3. A device according to claim 1 or 2, in which
10 the peak voltage of the pulsating direct voltage is about 5 KV.

4. A device according to claim 1, 2 or 3, in which the means for applying the pulsating direct voltage includes means for adjusting the peak value
15 of the applied voltage.

5. A device according to any of claims 1 to 4, in which the gap (12) between the electrodes is between 2mm and 5mm.

6. A device according to any of claims 1 to 5, in
20 which the electroviscous fluid comprises a suspension of particles in a liquid, the ratio by weight of particles to liquid being at least 1:1.

7. A device according to any of claims 1 to 5, in which the electroviscous fluid comprises a suspension
25 of particles in a silicone fluid.

8. A device according to any of claims 1 to 5, in which the electroviscous fluid comprises a suspension of particles in a silicone fluid, the ratio by weight of particles to liquid being at least 1:1.

9. A device according to claim 8, in which the
30 viscosity of the silicone fluid is between 1 and 500 centistokes.

10. A device according to claim 9, in which the viscosity of the silicone fluid is about 350 centi-
35 stokes.

11. A device according to any of claims 6 to 10, in which said particles are hygroscopic. .

12. A device according to any of claims 6 to 11, in which the particles comprise starch.

5 13. A device according to any of claims 6 to 12, in which the ratio by weight of particles to liquid is not substantially more than 1.8:1.

10 14. An electroviscous fluid comprising a suspension of particles in a liquid, characterised in that the ratio by weight of particles to liquid is at least 1:1..

15 15. An electroviscous fluid comprising a suspension of particles in a liquid, characterised in that the liquid is a silicone fluid.

16. An electroviscous fluid according to claim 14 or 15, in which the ratio of particles to liquid is not substantially more than 1.8:1.

17. An electroviscous fluid according to claim 14, 15 or 16, in which the particles comprise starch.

20 18. A device according to any of claims 1 to 13, which is a clutch or brake in which the electrodes are defined respectively by two relatively rotatable members (11,12) which are coupled together by said electroviscous fluid when said direct voltage is applied to
25 said electrodes.

19. A device according to claim 18, which is a vehicle brake fitted with an anti-wheel lock system.

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